

Statics

Session Aims

- ❑ **Introduce the different types of Static Corrections**
- ❑ **Explain why Static Correction is required and its effect on seismic data**
- ❑ **Describe methods of deriving the information required to apply static corrections**
- ❑ **Perform practical exercises in deriving statics**

Definition

Static corrections, generally shortened to just 'statics', are time-shifts applied to seismic data to compensate for:

- **Variations in elevations on land**
- **Variations in source and receiver depths (marine gun/cable, land source)**
- **Tidal effects (marine)**
- **Variations in velocity/thickness of near-surface layers**
- **Change in data reference times**

Term 'static' used to denote constant time-shift of whole data trace, as opposed to variable time-shifts as applied by normal moveout correction (NMO) which are 'dynamic'.

Illustration-1

Model
with
flat
surface and
constant
velocity

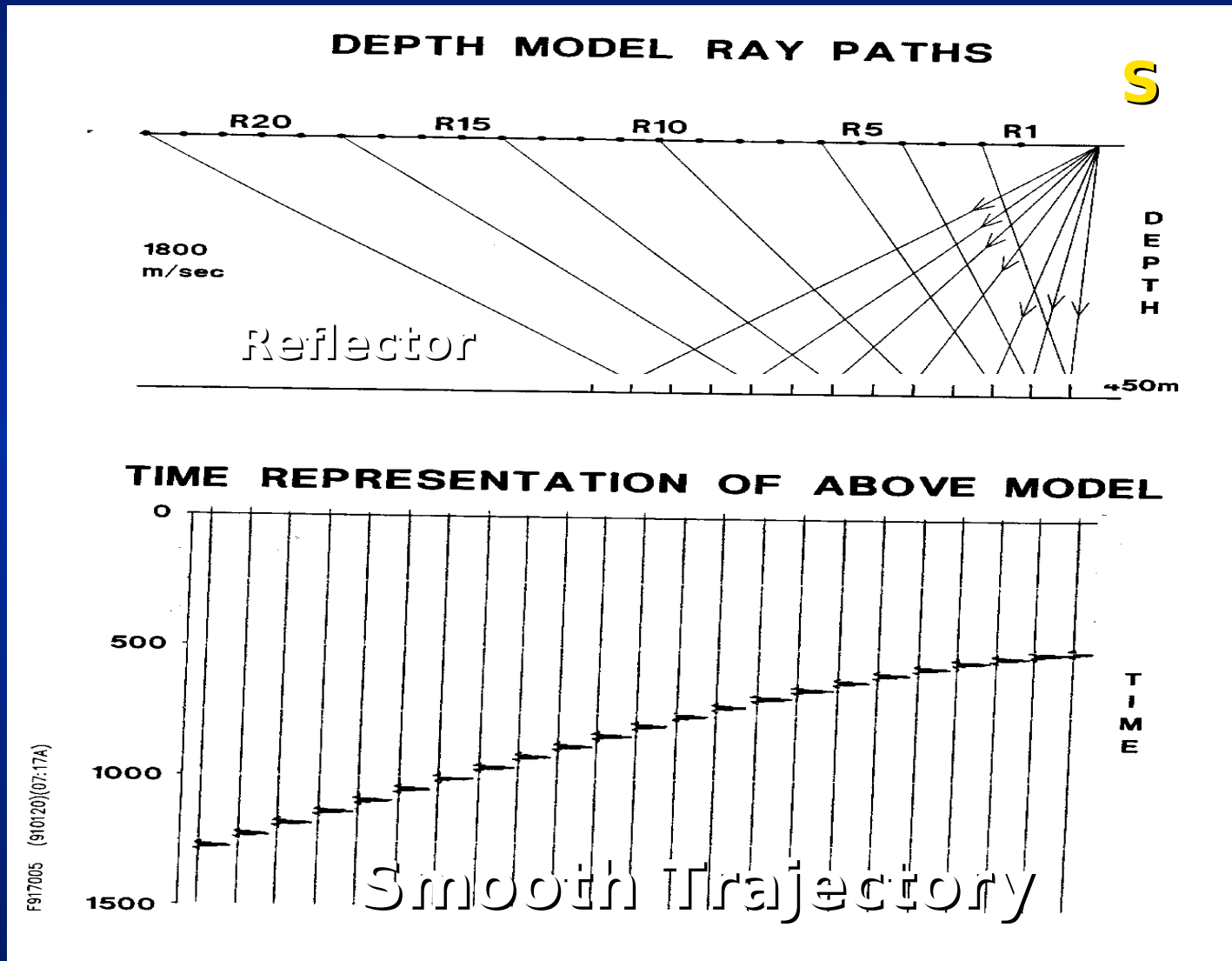
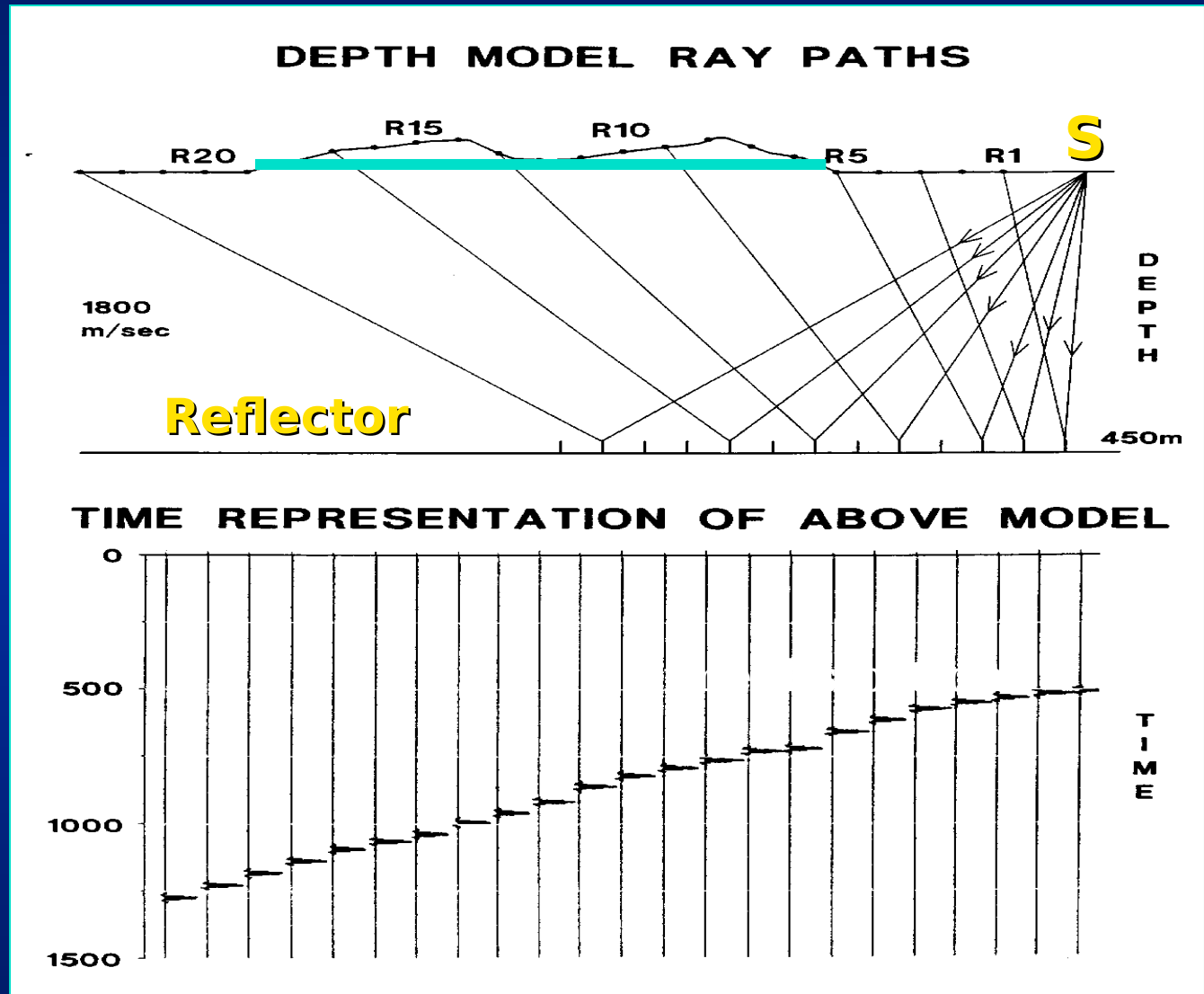


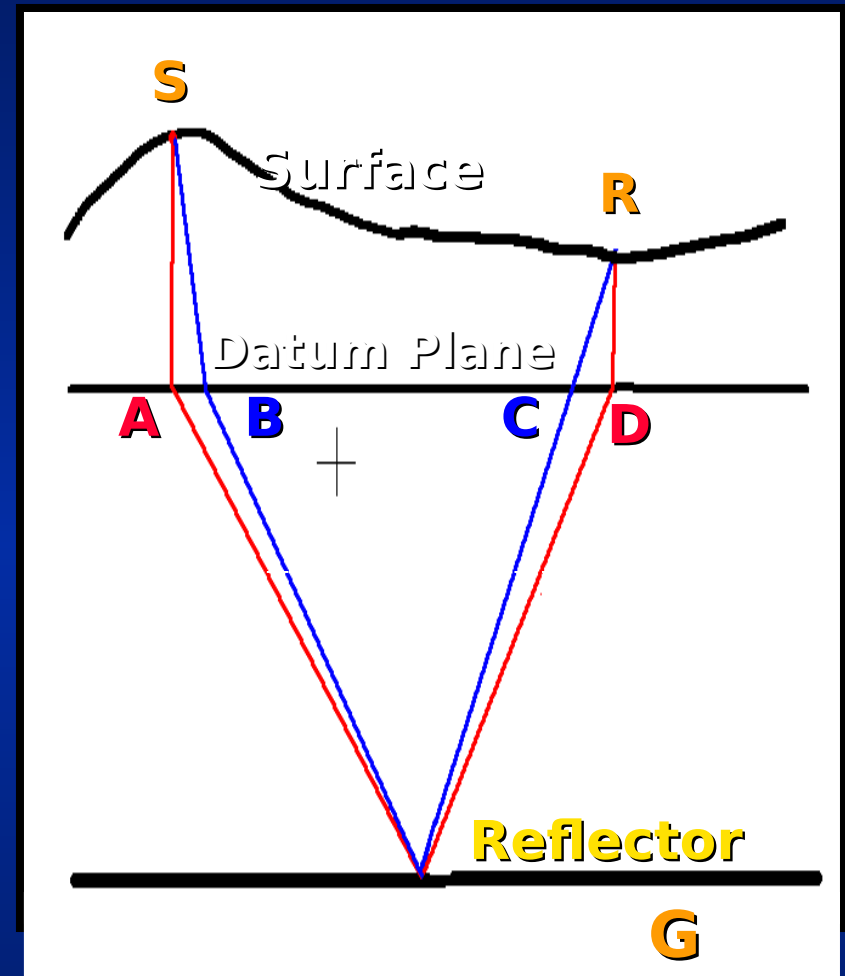
Illustration-2

Model with
non-flat
surface but
constant
velocity



Static Assumptions

- The ray-paths through the near-surface layering are vertical (not quite true)
- This means that deeper the reflector, better the assumption. This also means that shallow data is likely to suffer if weathering is thick
- 2- Weathering medium is isotropic



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$$SA + AG + GD + DR = SB + BG + GC + CR$$

Main Types of Static Corrections

- **FIELD (Initial) STATICS**

The main static correction based on field measurements/derived from data acquired in the field e.g. up-hole survey, refraction data.

- **RESIDUAL
STATICS**

derived during processing by using reflection data to 'fine-tune' the field statics

Why apply 'statics'?

Consider the following (simple) earth model -

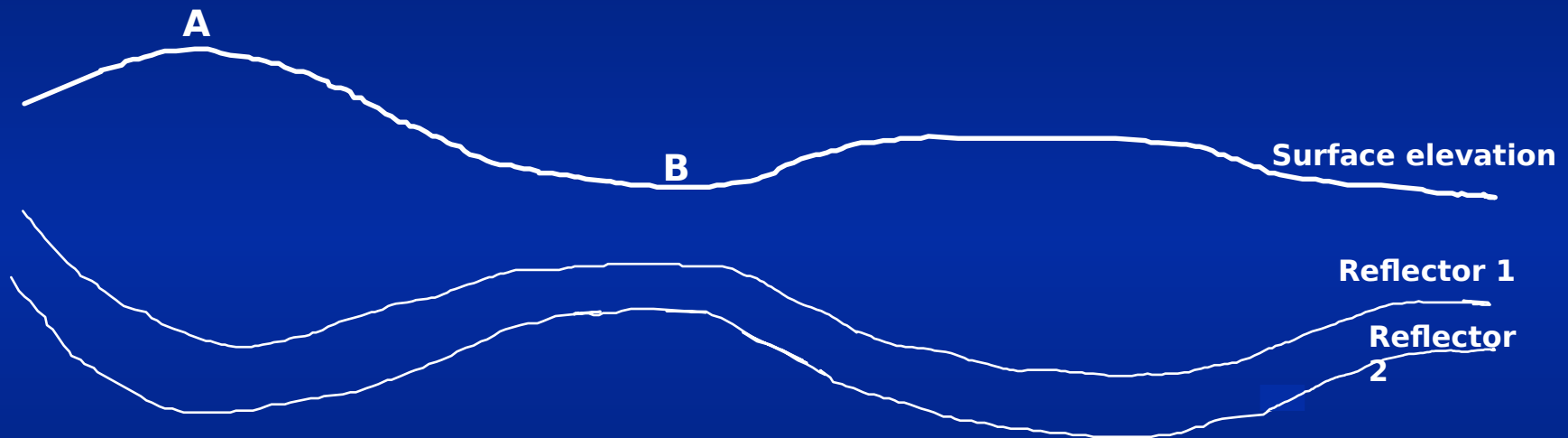


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Assuming constant velocity of propagation in each layer, the reflection time for data shot/recorded in the vicinity of A will be greater than that in the vicinity of B.

Why apply 'statics'?

Without any 'corrections', our time-referenced stacked data would look something like this -

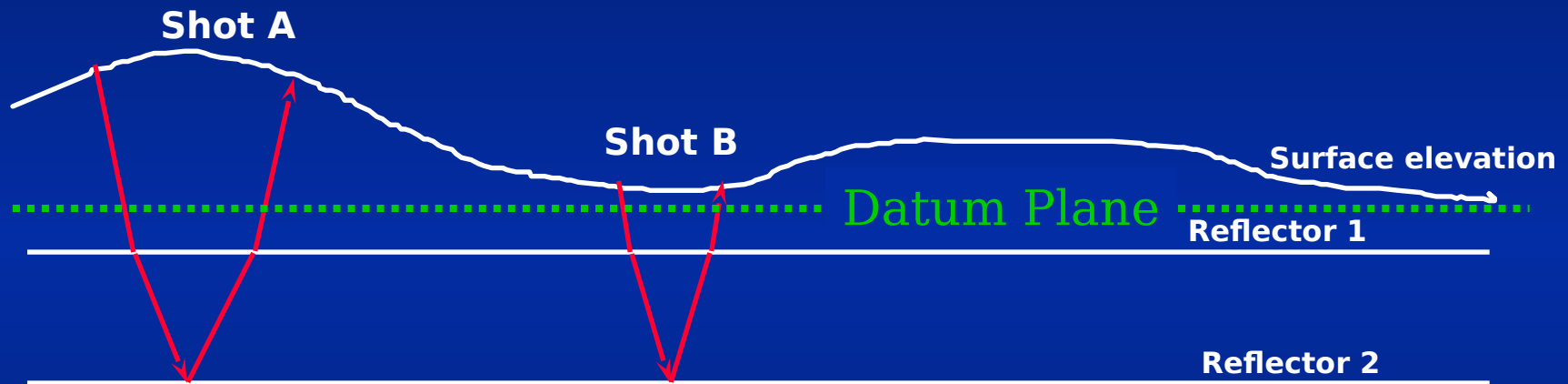


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reflectors 'mirror' the surface elevation and do not represent the true sub-surface.

Why apply 'statics'?

variations in the elevation introduces inaccuracies in the sub-surface model which need to be compensated for.

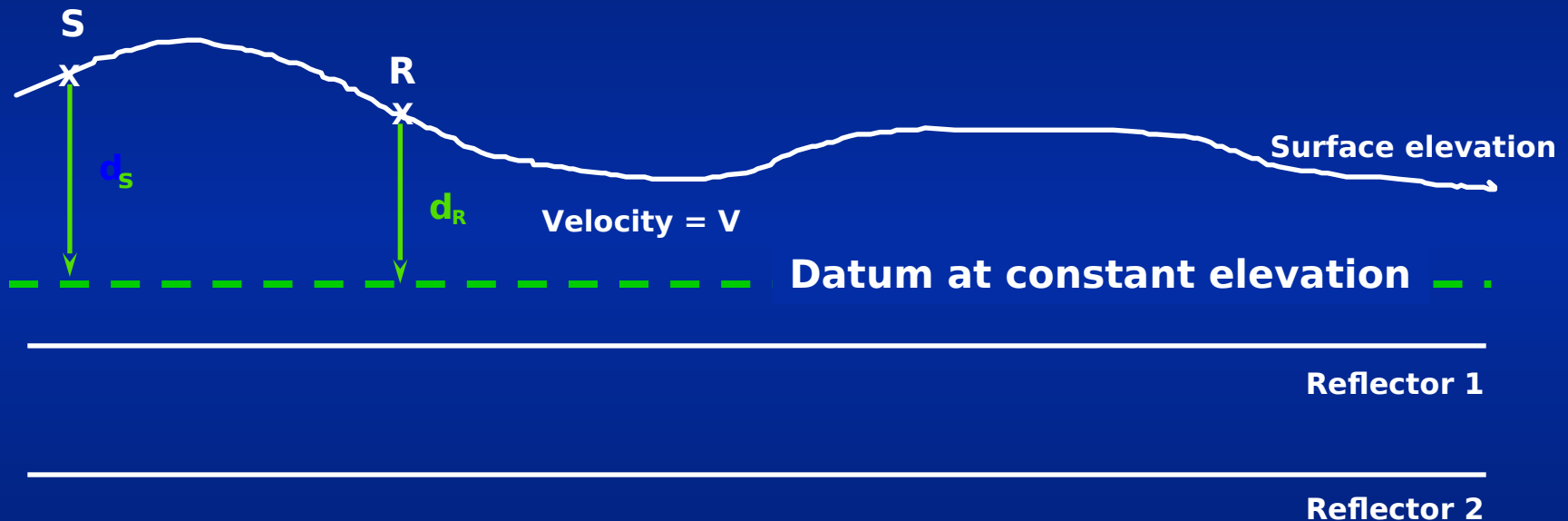


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is achieved by applying a static correction to a flat, horizontal plane known as a “**Datum Plane**”. It is generally at a fixed elevation below the **weathering** (unconsolidated layers in the near-surface).

Static Concept

- Effectively move all sources and receivers from surface to datum



d_s and d_r represent elevation differences of shot and receiver above the datum plane respectively

Surface Consistency

- **We calculate static values that are surface-consistent**
- **It means that a static value at a particular location is the result of local surface and near-surface conditions and affects equally all seismic measurements made at that location**
- **In this context , a surface source and receiver at the same location will have the same static value.**

Sign Convention

✗ Negative shift

Data is moved upwards towards time-zero

i.e. reflection times decreased

✗ Positive shift

Data is shifted downwards away from time zero

i.e. reflection times increased

Some contractors/clients have been known to use the opposite convention - unusual, but always check!

Information required for static derivation

- surface elevation and X-Y co-ordinates of source and receiver locations
- Velocity of weathering layers
- Thickness of weathering layers
- datum plane elevation
- velocity from base of weathering to datum - often referred to as datum correction velocity or replacement velocity

Source of information

Surface elevations - measured in the field

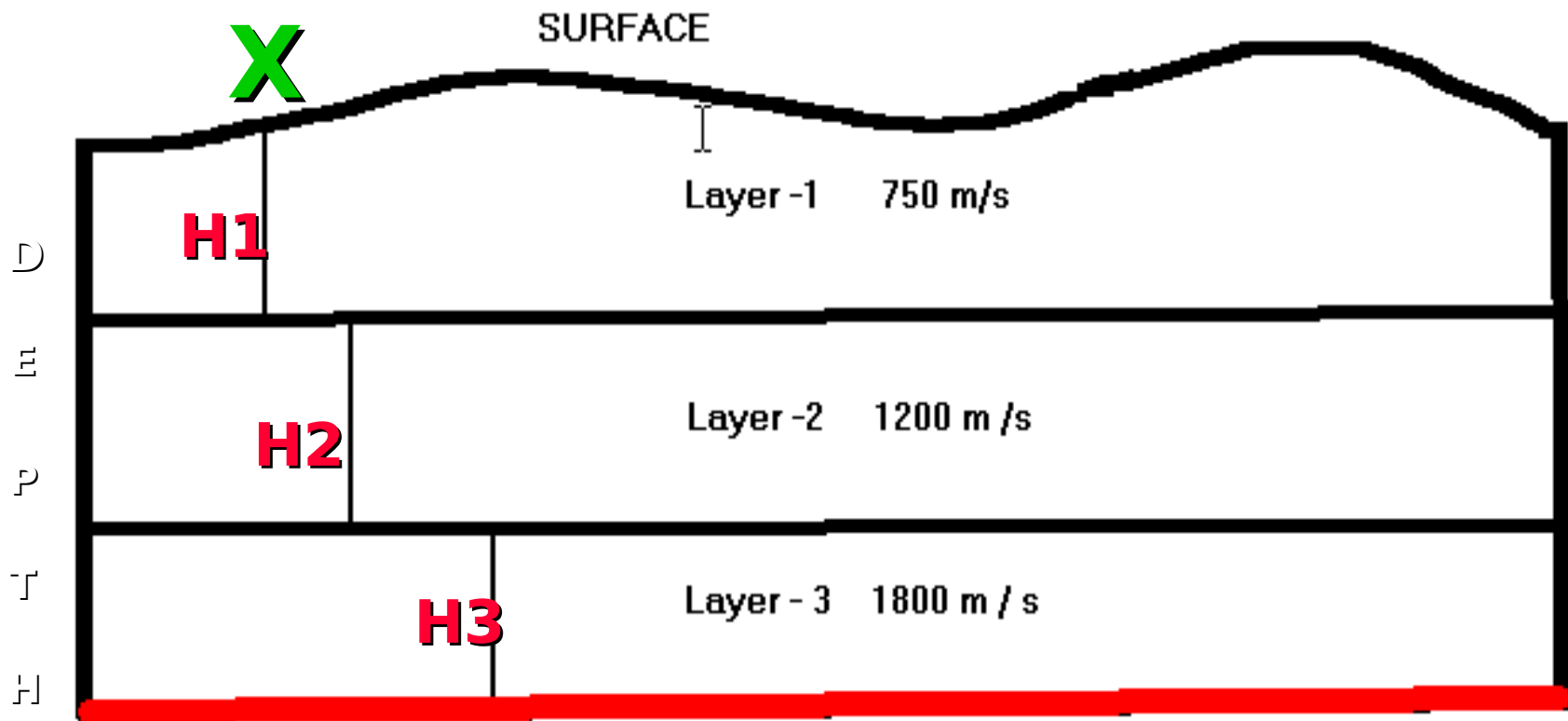
Water level elevation - usually from the client and usually depends on the surface elevation and historic precedence.

**Refraction Or
Placement
velocity** - historical values or can be measured during low-velocity-layer survey or via uphole surveys

**Weathering velocities
and weathering
thicknesses** Upholes & Refracted arrival analysis

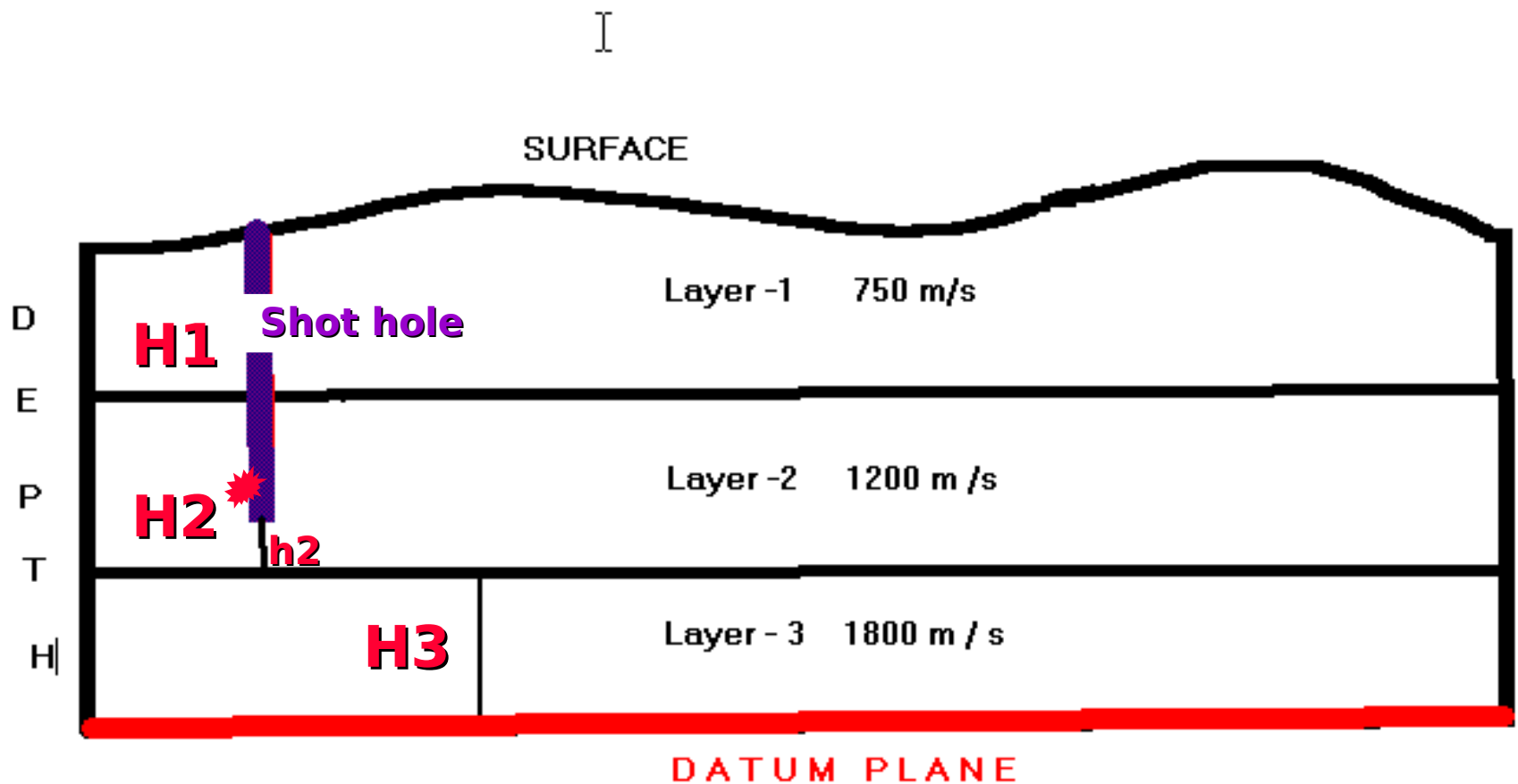
Simple Static Model

One-way
correction (at X) = - (H1 /750 + H2 /1200 + H3 /1800



Case of a Buried Source

Static correction (at X) = - (**h2** / 1200 + **H3** / 1800)



Weathering Static Corrections

Weathered layers are -

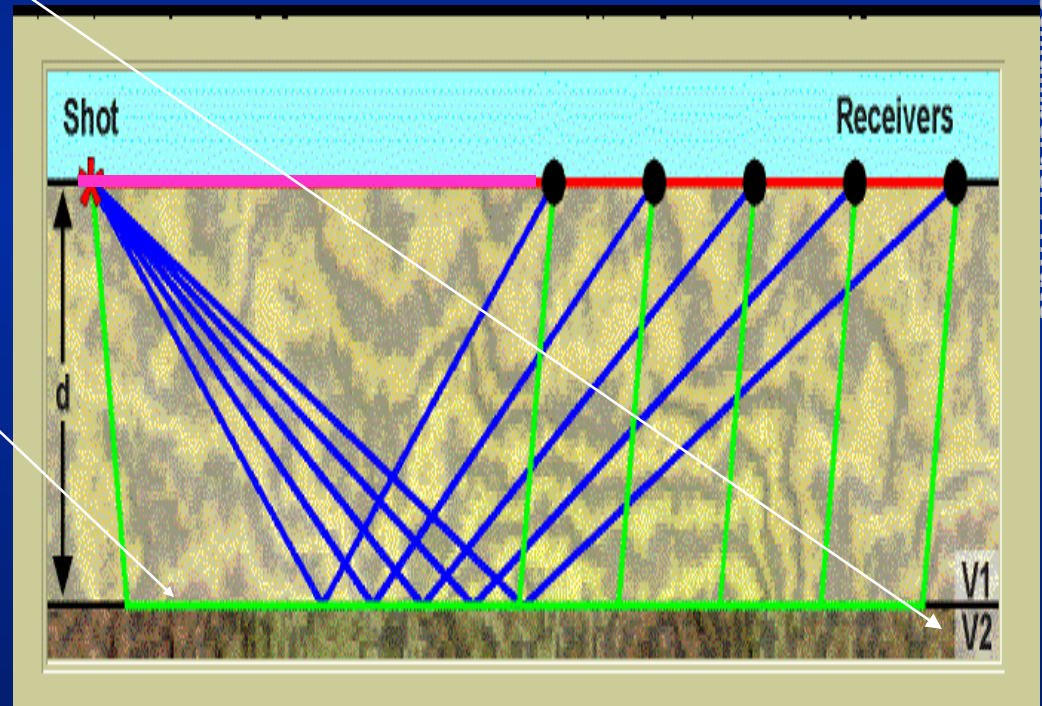
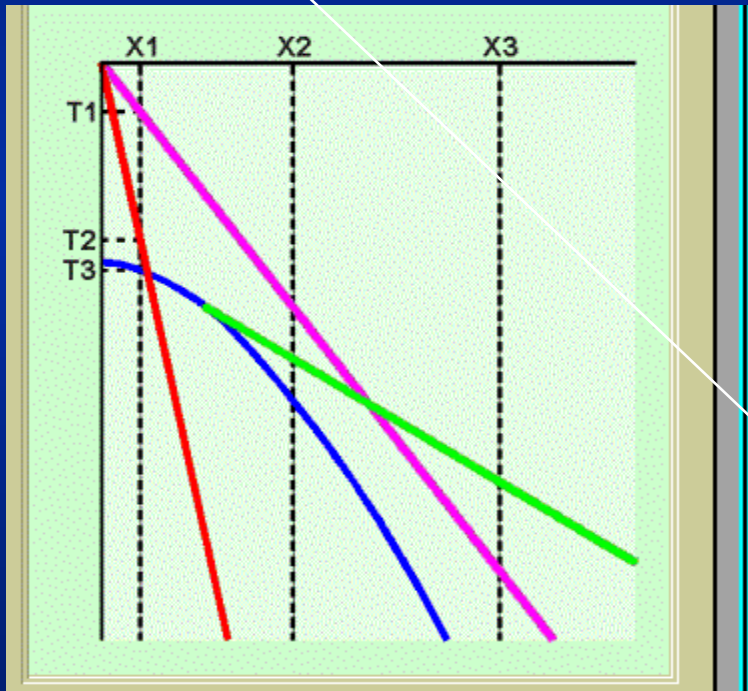
- **Near surface**
- **Unconsolidated (low density)**
- **Low velocity**
- **Act as filters, attenuate amplitudes in a frequency dependent fashion**
- **distort signal phase information.**
- **DELAY the seismic wave/ray.**

Static corrections are designed to compensate for these layers in addition to correcting for elevation differences

The travel path of refracted energy

After a certain offset the refracted energy will arrive at the receiver before the reflected energy.

This is because although the refracted energy has further to go, it travels at the faster V_2 velocity when travelling along the Interface.

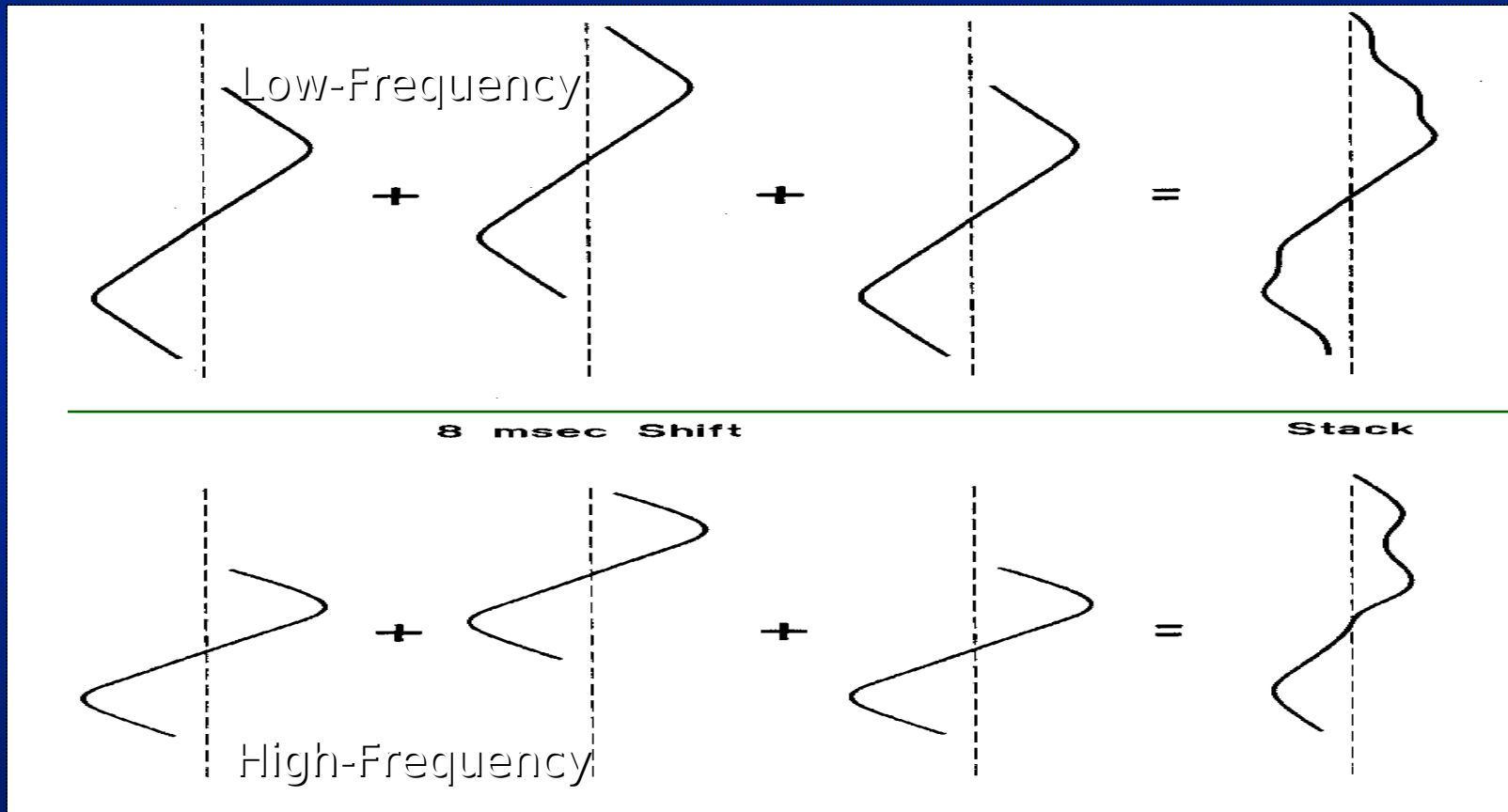


— Direct Arrivals
— Refracted Arrivals

— Reflected Arrivals
— Ground Roll

The Effects of Frequency Content

Static problems are more evident in
higher frequency shallow data



Short & Long-wavelength Statics

Short-wavelength (high-frequency)

Jitters- from trace-to-trace (fine tuning performed by residual statics corrections)

Long-wavelength (low-frequency)

From place-to-place- giving rise to a structural look

Residual static algorithms are not designed to deal with long-wavelength static problems. So solve them at initial stage. For this, refraction-based initial static solution is more suitable

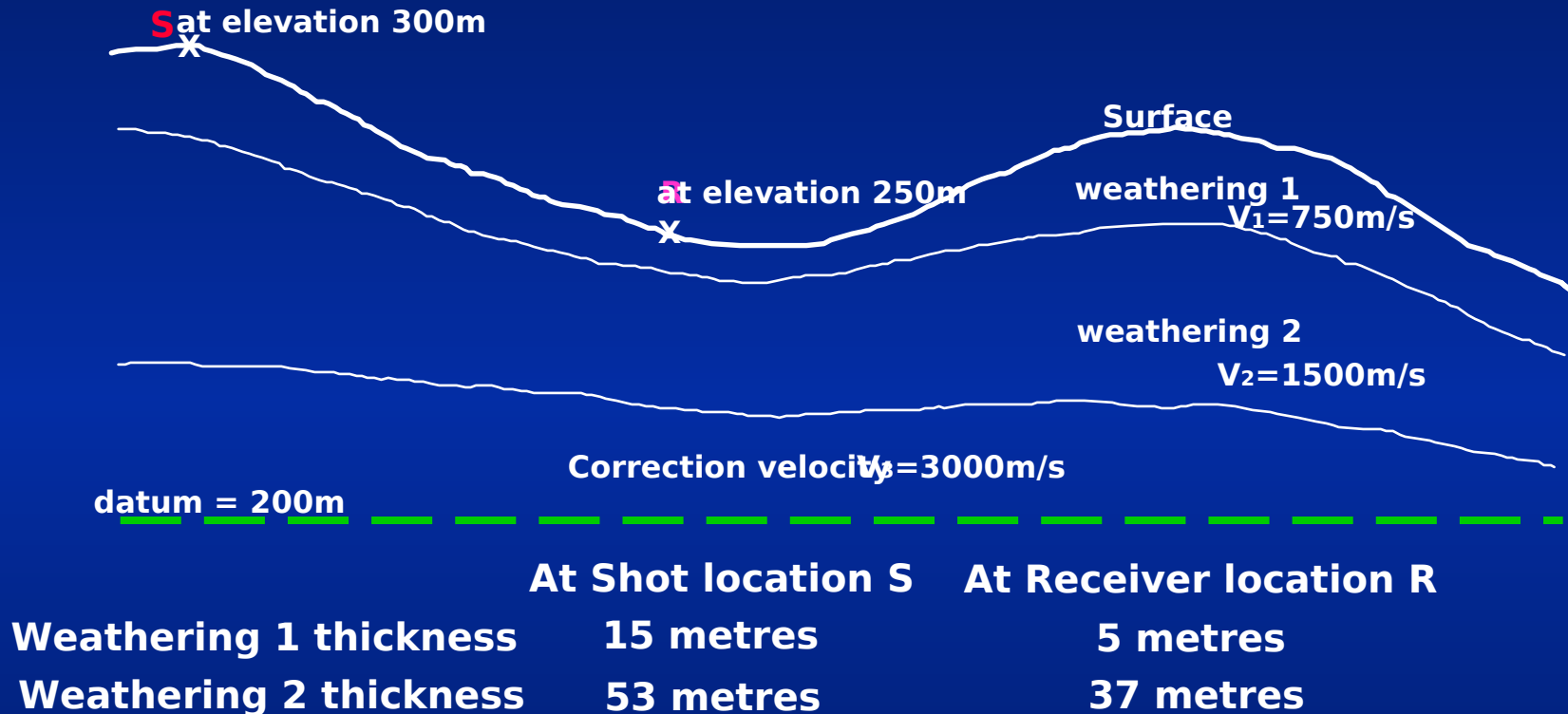
Sequence in Static Computations

If both elevation and weathering corrections are to be computed for a given near-surface model, the correct procedure is to:

Apply total weathering corrections first!

and then the corrections from base of weathering to the final datum elevation by using a laterally constant correction velocity.

Practical exercise 1.



Calculate the total static for correction to datum for data originating at S and received at R. Remember the sign convention.

Recap

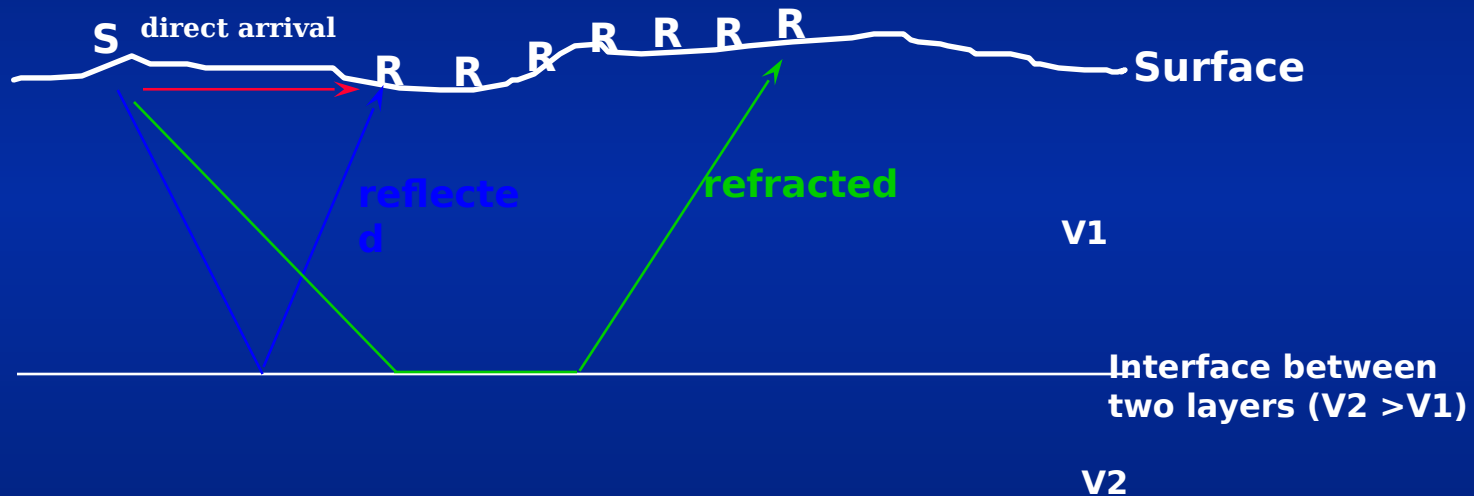
To calculate static value for a given trace, we need to know the:

- locations and surface elevations of receiver/source positions
- elevation of the datum plane
- laterally constant replacement (correction) velocity
- thickness of weathering layers and velocity through them

The first three are almost always known or provided.

Definitions

Direct, reflected and refracted arrivals



Three types of waves can be used to derive the required information to compute statics

Methods & Tools

- **Up-hole survey-** (uses direct arrival time)
- **LVL survey** - (based on refracted arrivals)
- **Normal shot records** - (based on refracted arrivals)

A combination of these methods is often used in deriving necessary information to compute field statics

Uphole Surveys

Holes are drilled (typically 50-100m) and shots detonated at varying depths.

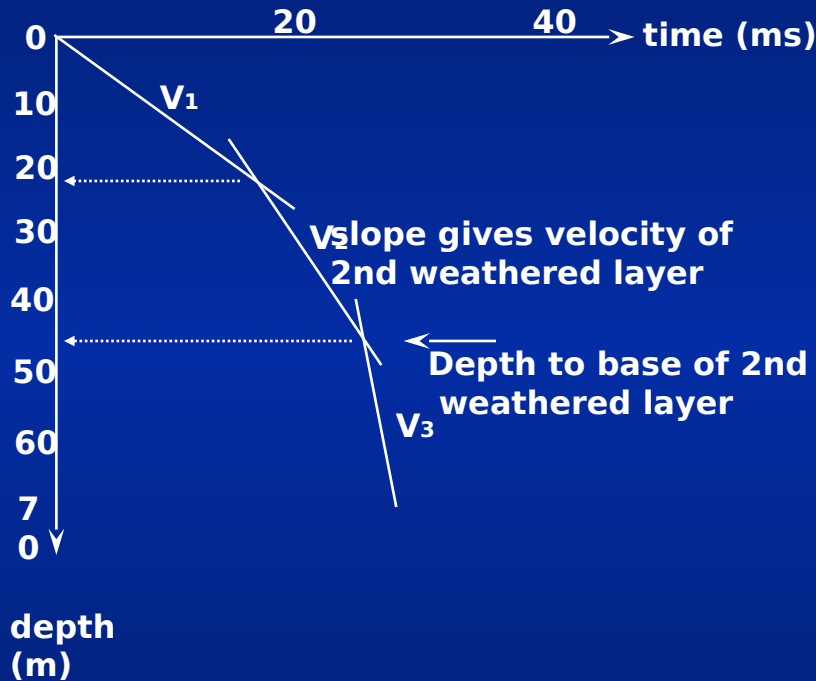
Depth of holes should just penetrate into the consolidated layer but will depend on time and cost factor.

Uphole times are recorded at geophones close to the top of the shot-holes.

Plots are made of shot depths vs uphole times

'Best fit' lines drawn through the plotted points to obtain velocities and thicknesses of weathering layers

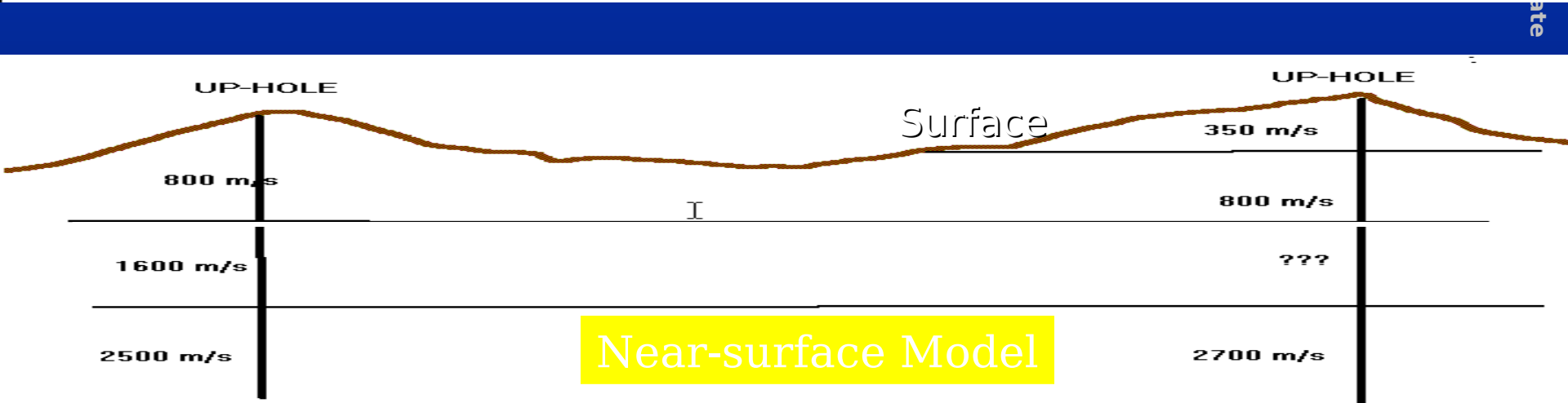
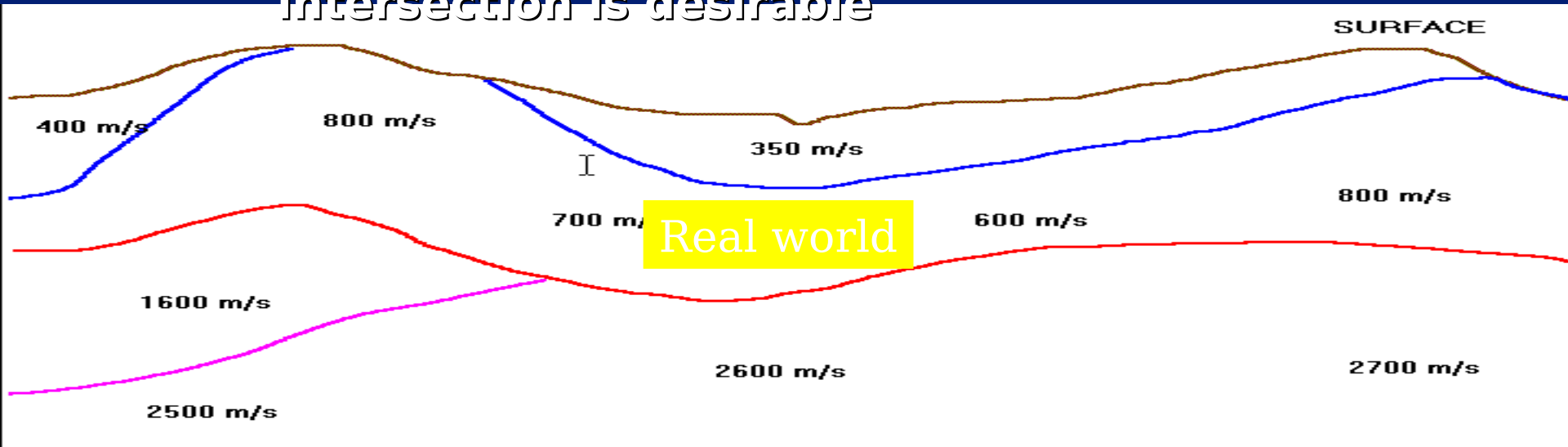
Up-hole Plot



Up-hole information recorded along a line/survey is interpolated to obtain a near-surface model to calculate statics

The Problem With

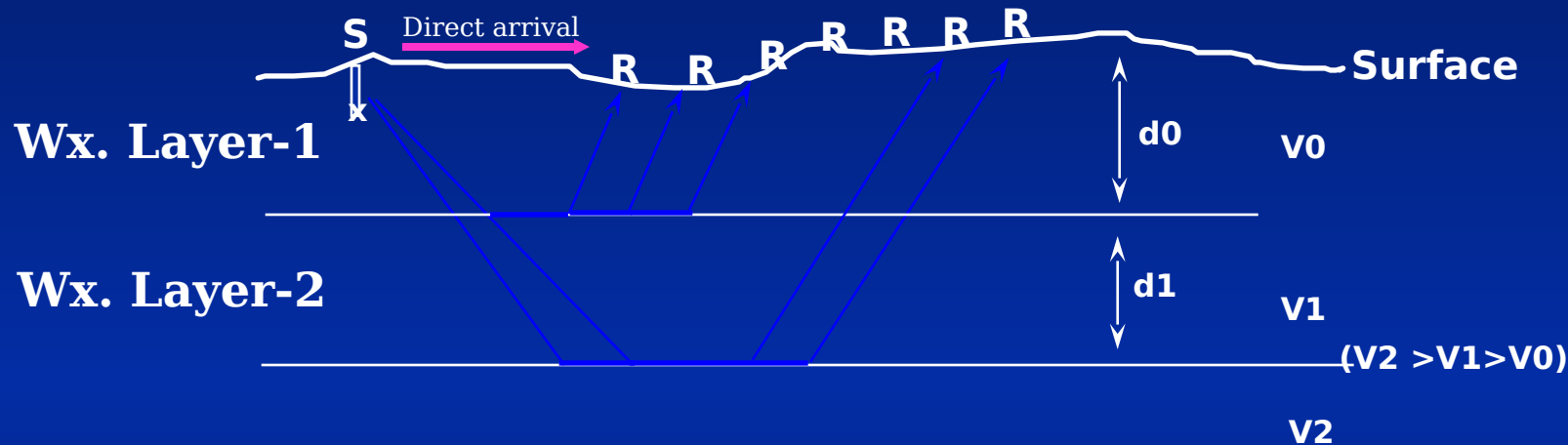
Up-holes
Ideally, a deep hole at every 2D line intersection is desirable



In this case, it is difficult to construct earth model with accuracy

LVL Survey

(Low-Velocity-Layer Survey)



- **Times for refracted arrivals measured as a function of offset.**
- **Also utilises time of direct arrivals**

LVL Survey

shot  ← Variable distance  shot

Provides similar information as up-holes

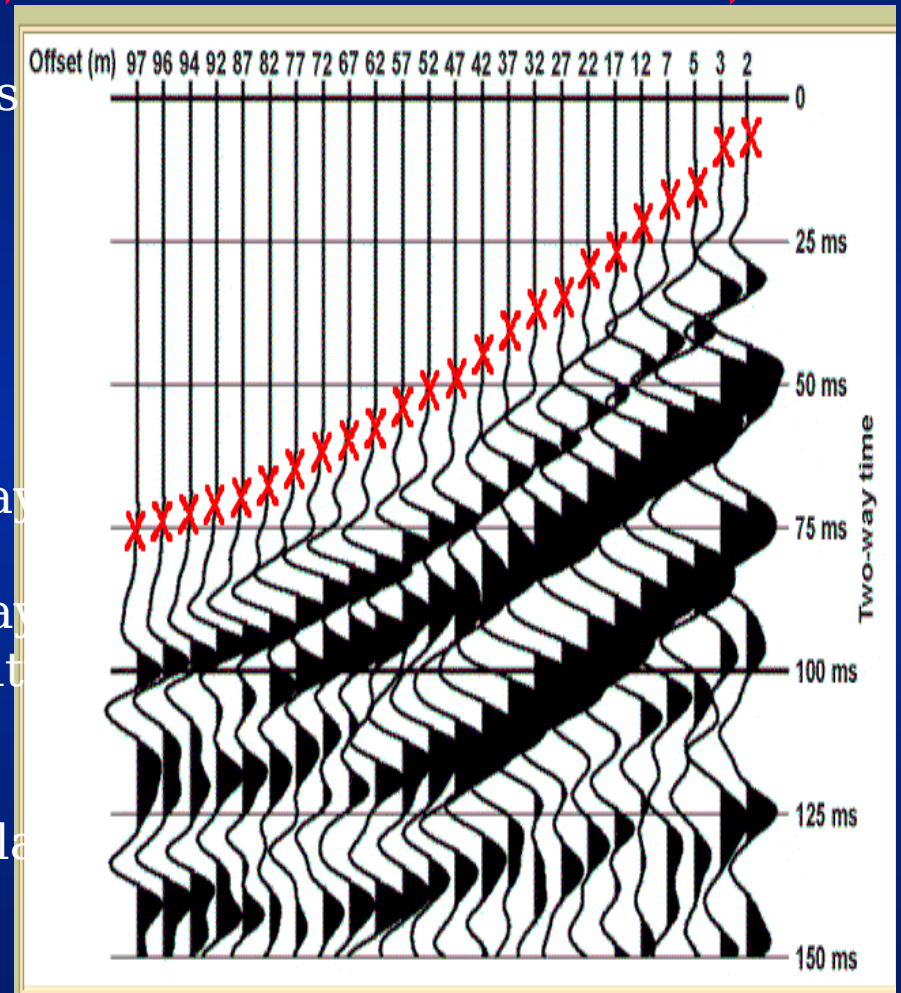
Single specialized geophones are used

A short split-spread cable provides a continuous coverage along a profile

The first-breaks are picked in normal way

Picked times are plotted in the same way as the up-hole plot to obtain layer velocity and layer thickness

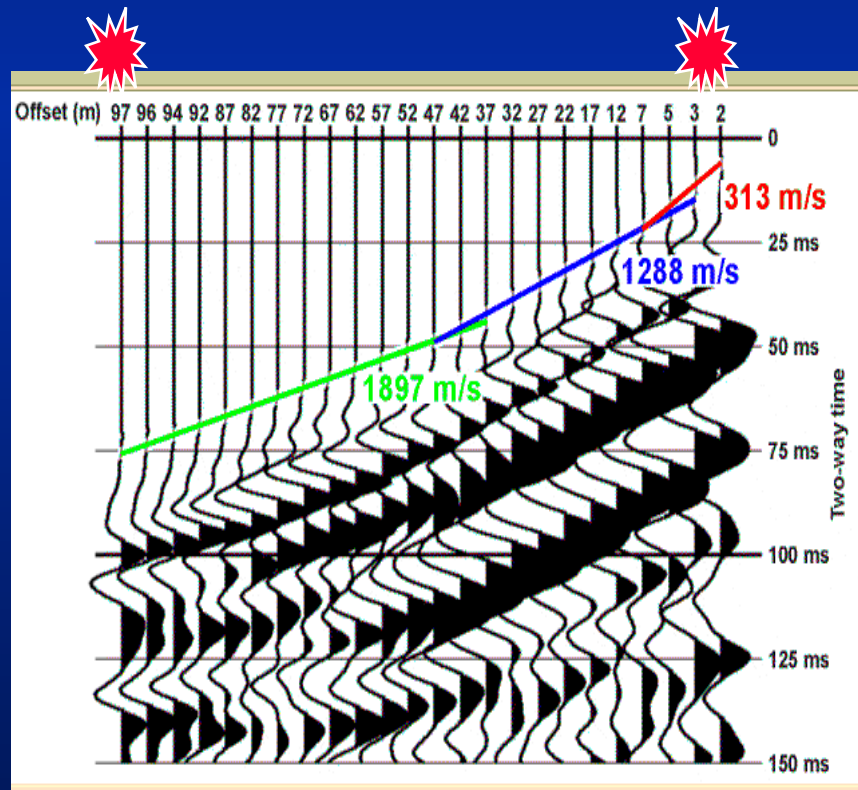
LVL survey is useful to choose datum plane elevation and correction velocity



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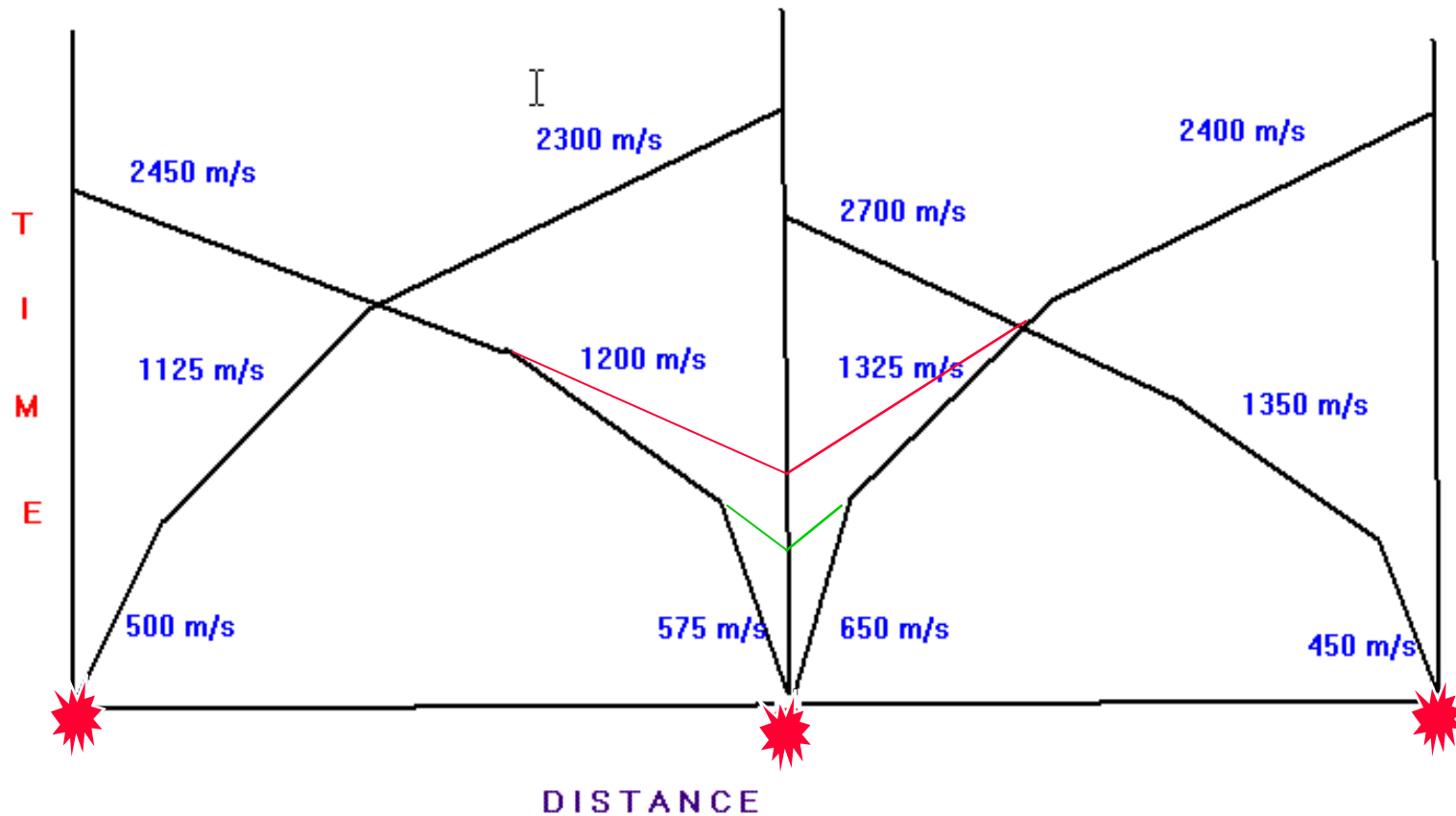
LVL Survey

- Time/Offset plots are made from shots at both ends of the spread to account for possible dipping layers or other anomalies
- As with up-hole survey, LVL survey is carried out at multiple locations along a line



Time-Offset Plots

$$z = \frac{T_i}{2} \frac{V_1 V_0}{\sqrt{V_1^2 - V_0^2}}$$



Statics from Shot Records

Generally known as 'first break' or 'refraction' statics

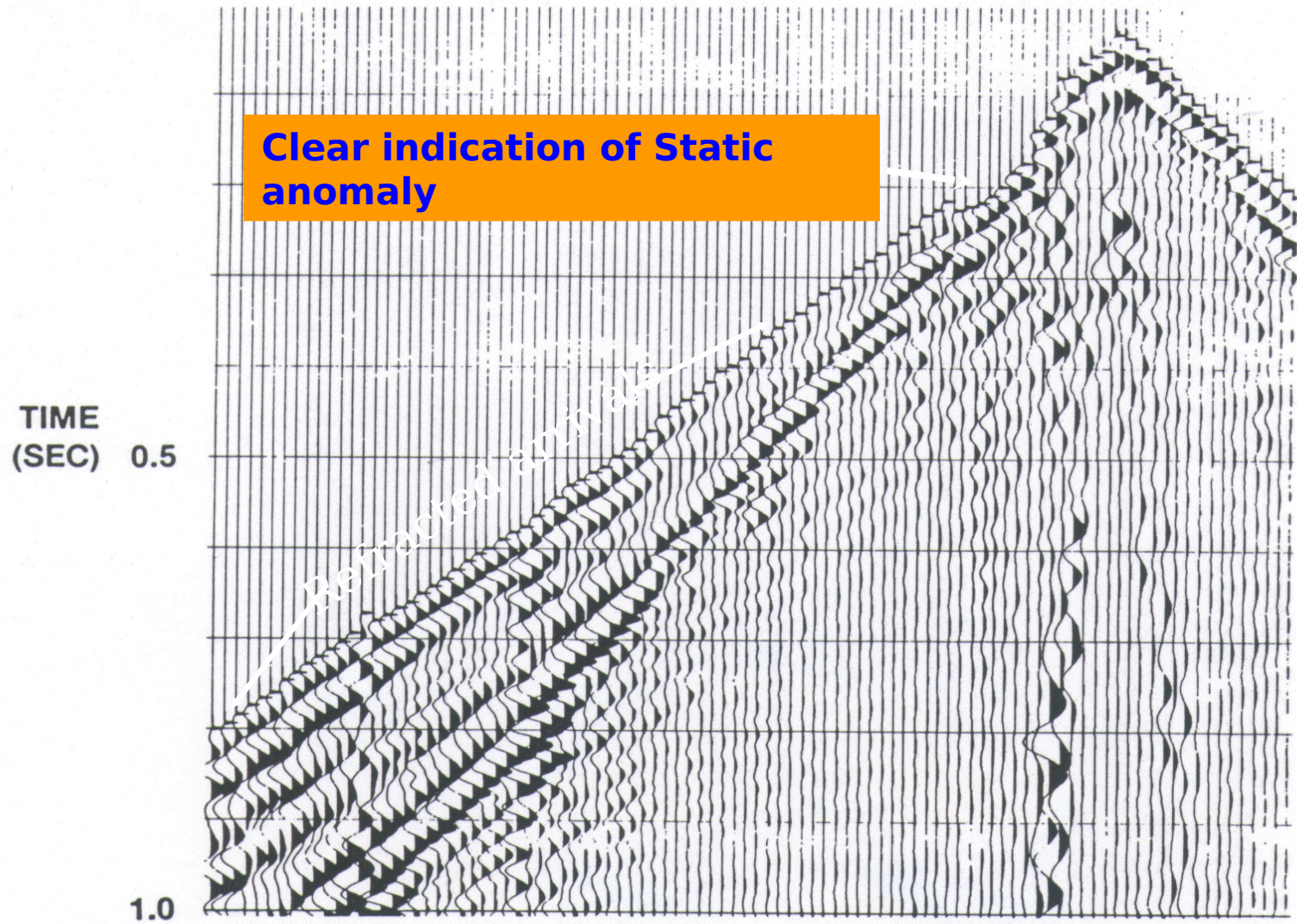
Refracted arrivals 'picked' from shot data records

First break - first recorded signal on a trace which is attributable to seismic energy from a common source

Probably the most widely used method of deriving field statics nowadays.

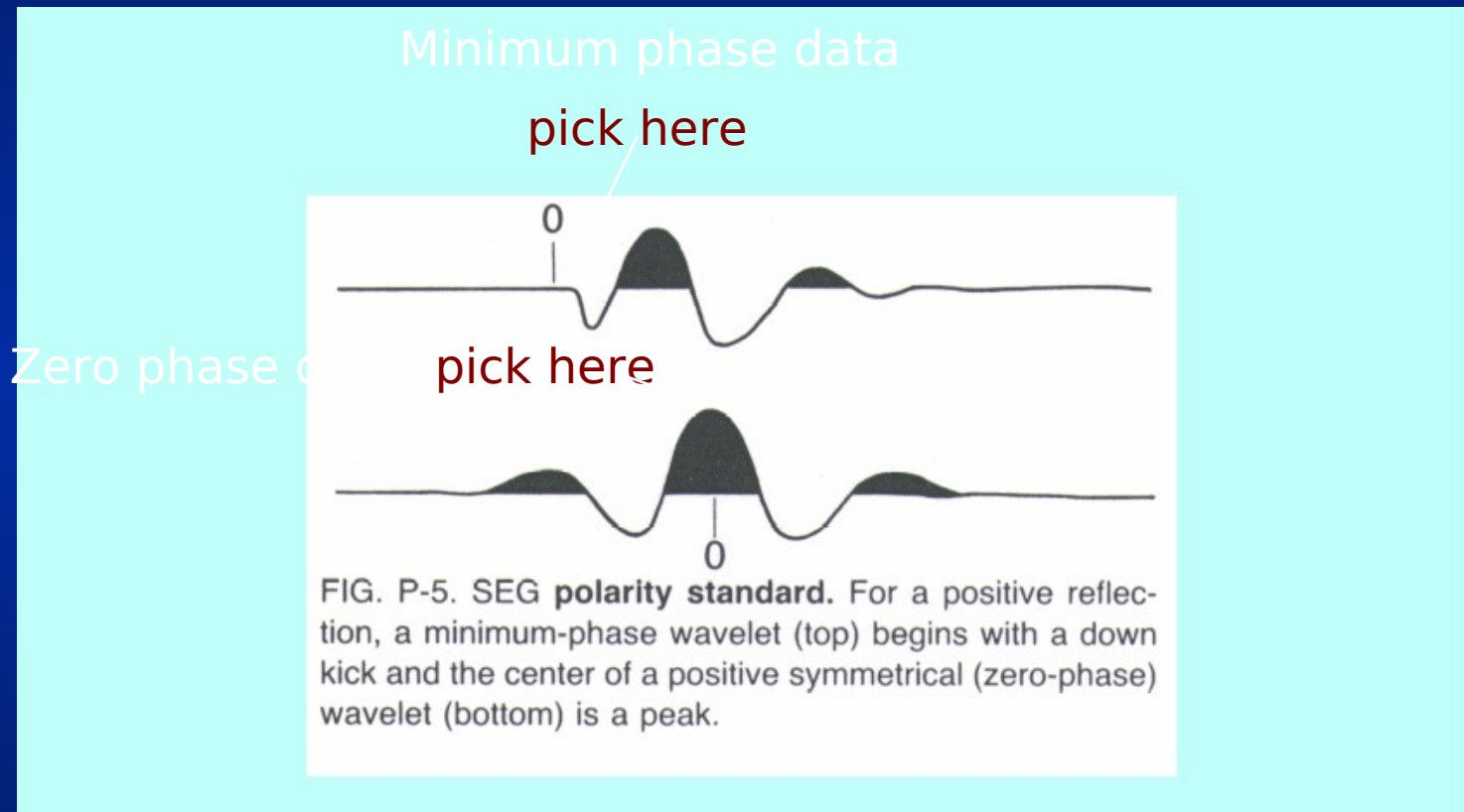
For the purpose of calibrating results obtained from refraction statics, often an up-hole survey is also conducted

Refracted Arrivals on Shot Records



Normal Shot Record

Pick Times - Phase Dependency



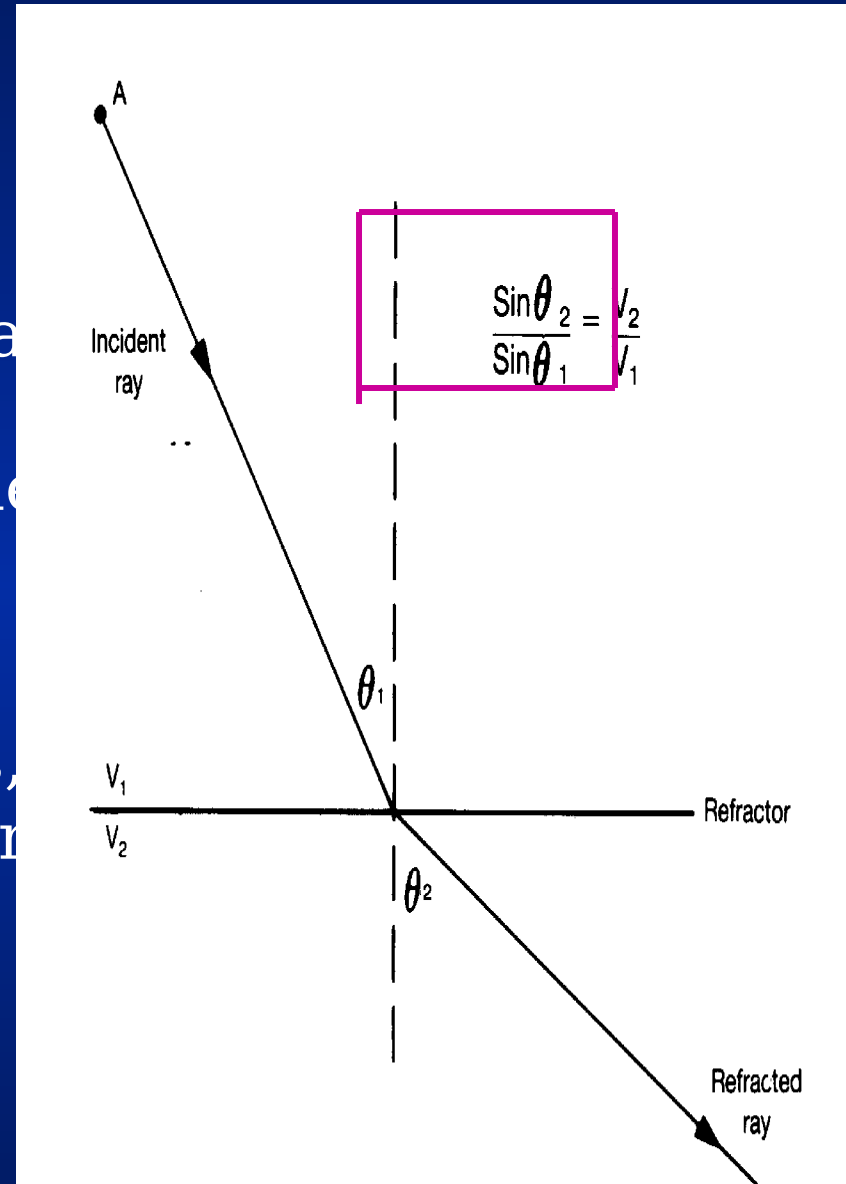
The Phenomenon of Refraction

The ratio of the Sines of angles is the ratio of velocities (i.e., the incident angle and the angle of refraction)-measured from normal

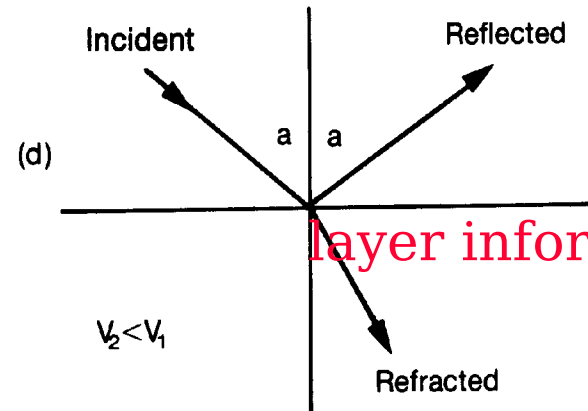
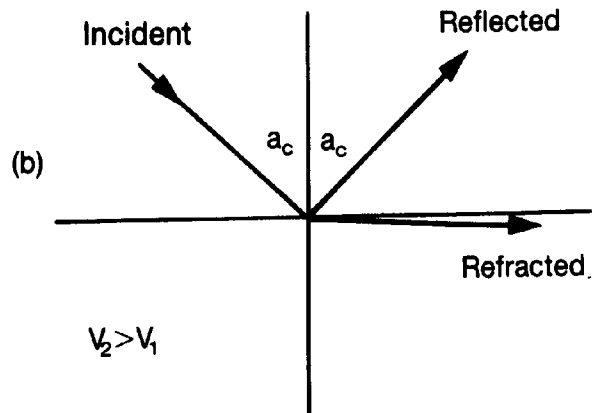
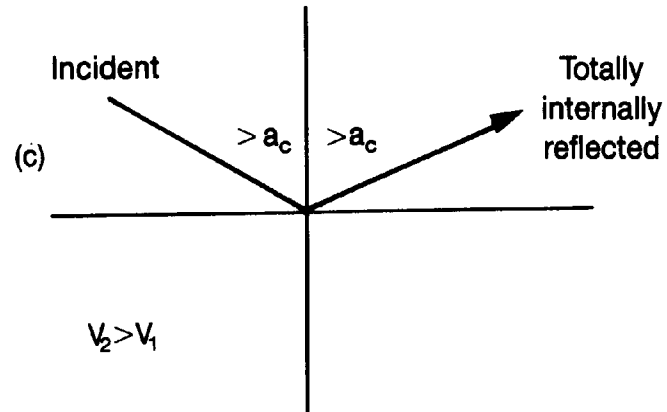
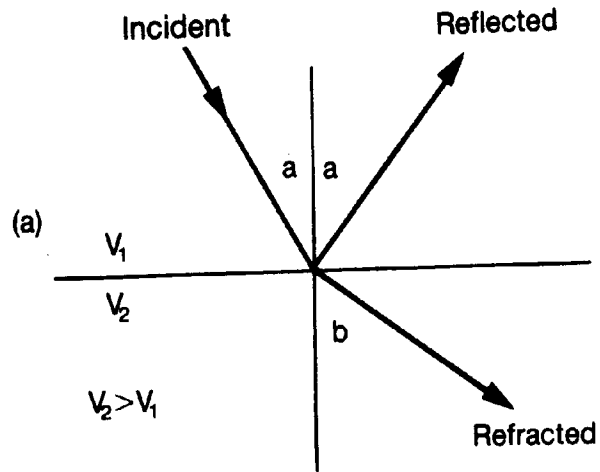
Critical angle is an incident angle for which the angle of refraction becomes 90 degree

If $V_1 = 1000\text{m/s}$ and $V_2 = 2000\text{m/s}$, then the incident angle of 30 degree will be the critical angle

$$\text{Critical Angle} = \sin^{-1} V_1/V_2$$



Reflection, Refraction & Transmission Mechanisms

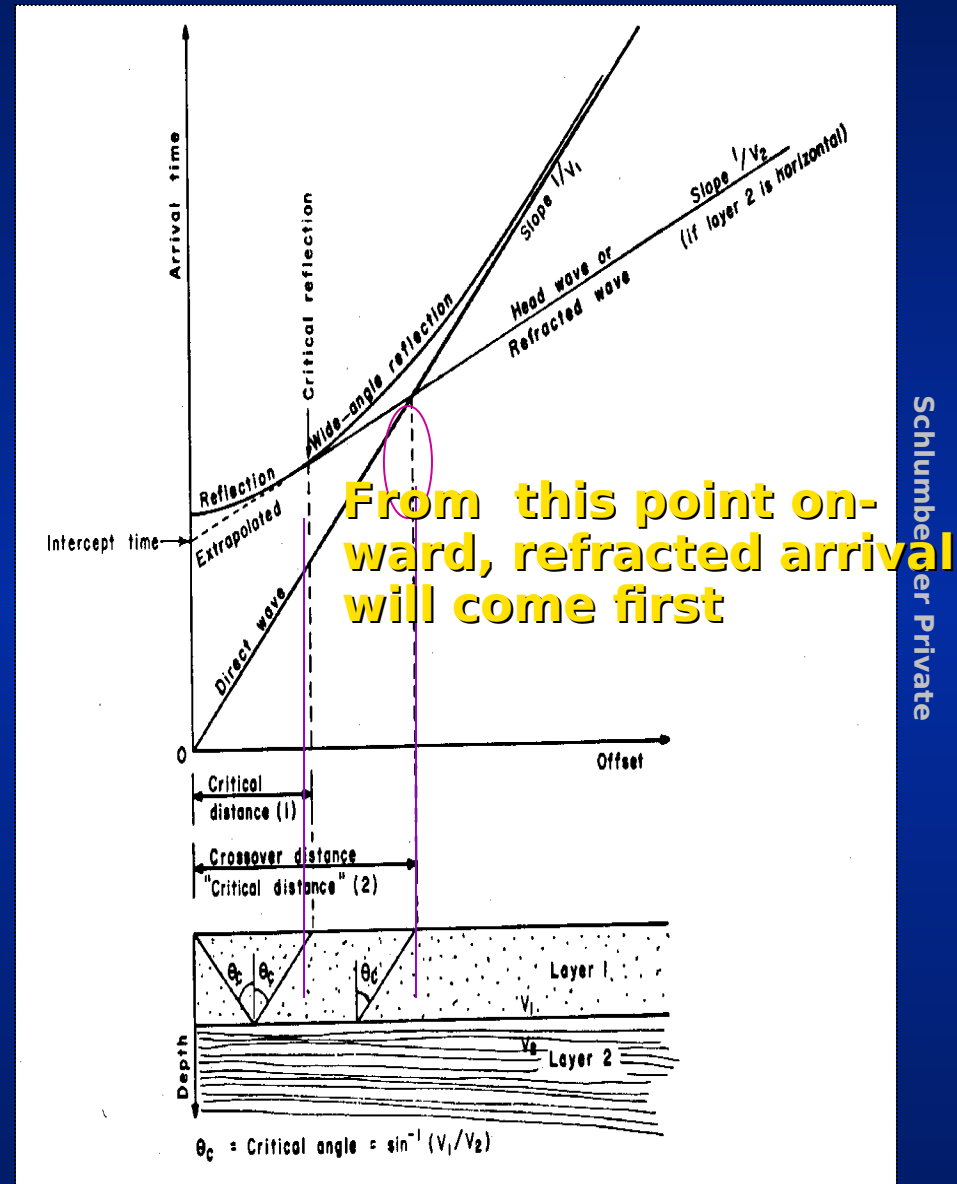


layer information is missed

Critical & Crossover Distances

Critical Distance: The offset at which the reflection time equals the refraction time

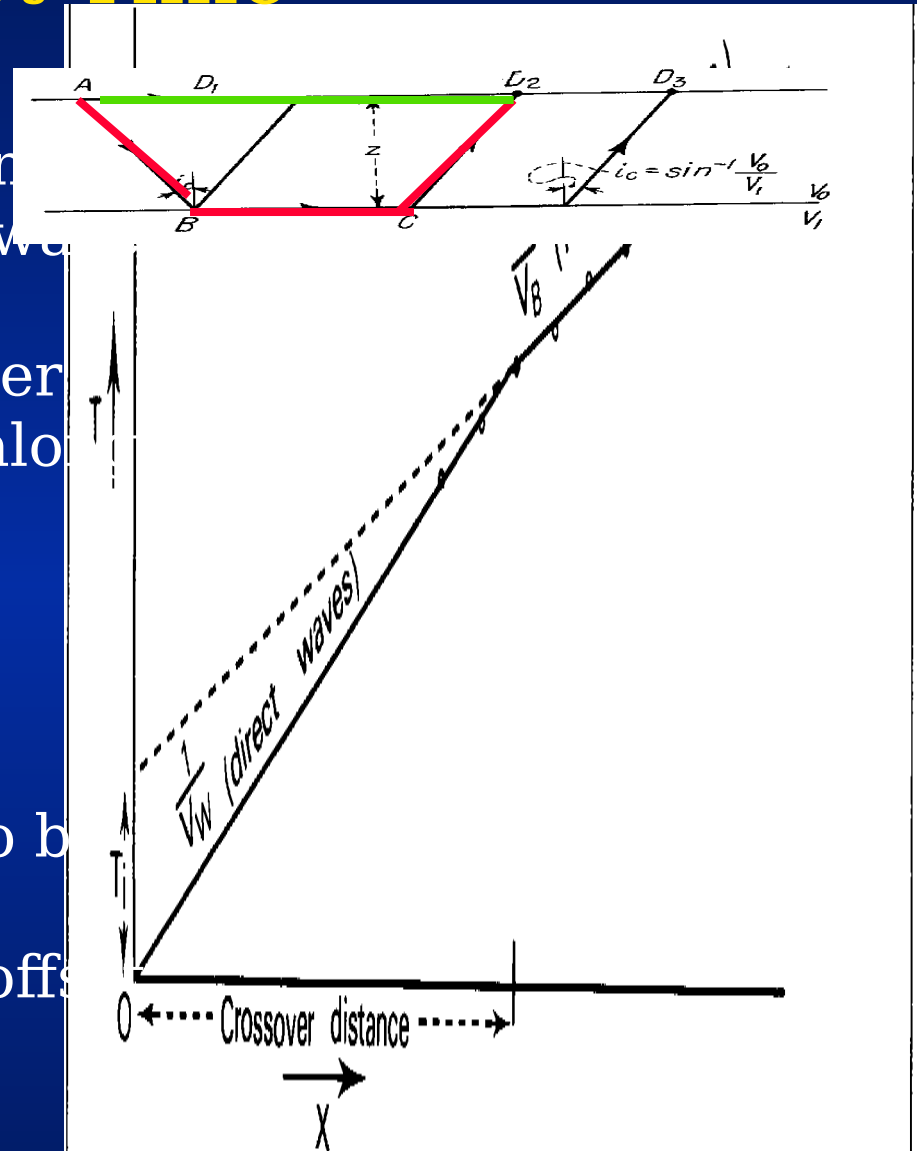
Crossover Distance: The distance at which a refracted event becomes the first break



The Intercept Time

Definition: The difference between the actual travel-time of the refracted wave and the time required to travel horizontally between shot & receiver at the highest speed encountered along the refraction path.

From a Time-Offset plot, it can also be worked out by extrapolating the refraction alignment back to zero-offset.



- Commercial software packages are available for analysing first-breaks and subsequent solving of the static solution
- **Green Mountain Geophysics (GMG)**
- **Hampson Russell**
- Main difference between different packages is method of solving for statics from measured time-shifts.

Types of Datum

- **CMP Datum Plane**
 - **Also known as floating datum**
- **Final Datum Plane**

CMP Datum Plane

- **Smooth, near-surface and surface-following**
- **Corrects for high frequency component of the total static for each seismic trace**
- **Small deviation from original reference times (i.e surface)**

Note - CMP datum is referenced by time, not elevation

CMP Datum Plane

- It is also called a 'Floating Datum Plane'
- Total statics correction to 'final processing' datum may involve large time shifts - data no longer at original time zero!
- Normal-moveout correction (NMO) requires that the reference time of our data be at the original time-zero, i.e., surface
- Need to apply some statics before NMO to account for the high frequency weathering statics and improve the resolution.

CMP Datum Statics

It is generally computed in two steps:

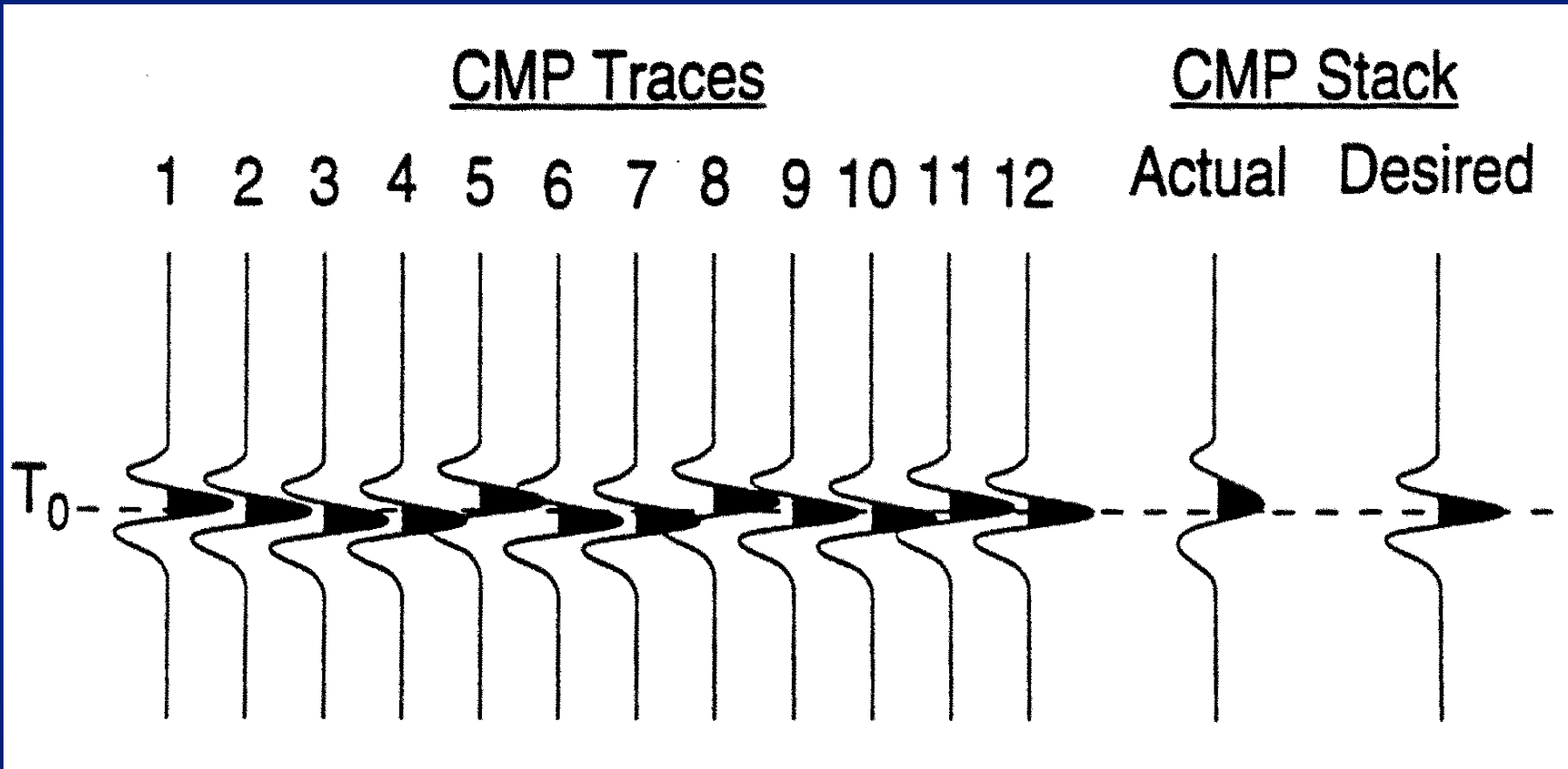
- a) First, the shot and receiver static values of all the traces in a CMP gather are summed together.**
- b) The total is then divided by the number of traces in the CMP to obtain an average value which is what we call “CMP Datum Correction”.**

Residual Statics Correction

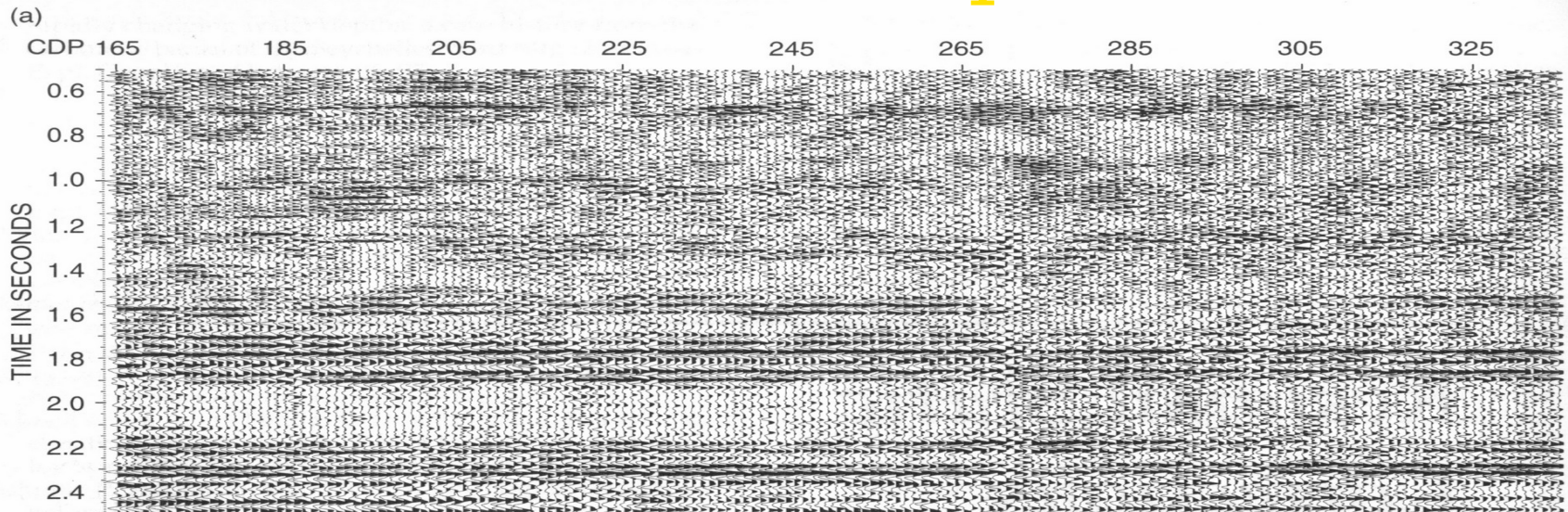
'field' (initial) statics do not generally solve all delays within the data for a variety of reasons, for example -

- Velocities vary both laterally and vertically within the layers
- Weathering thickness varies rapidly
- Undetectable thin, low velocity layers
- Local anomalies (e.g. 'lenses' of low velocity material near the surface)
- Vertical ray approximation is incorrect

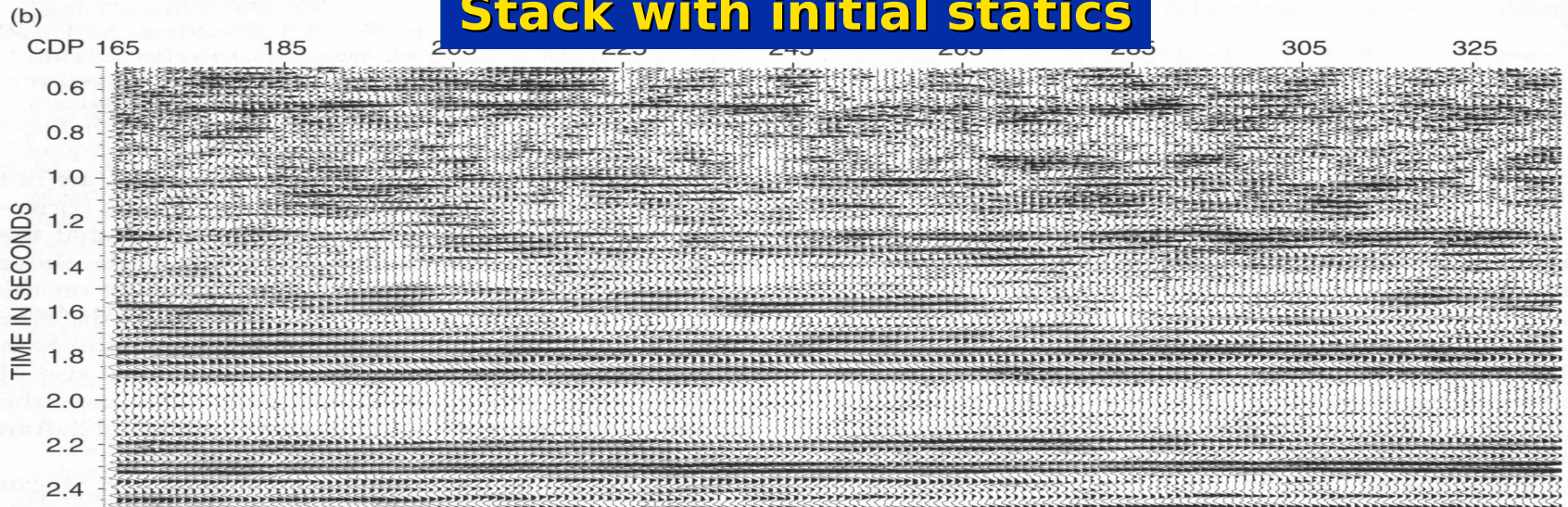
The Basic Approach



Data Example



Stack with initial statics

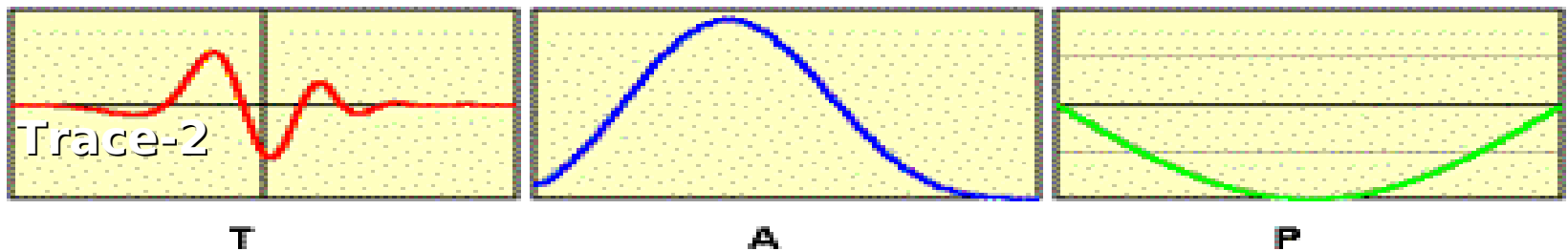
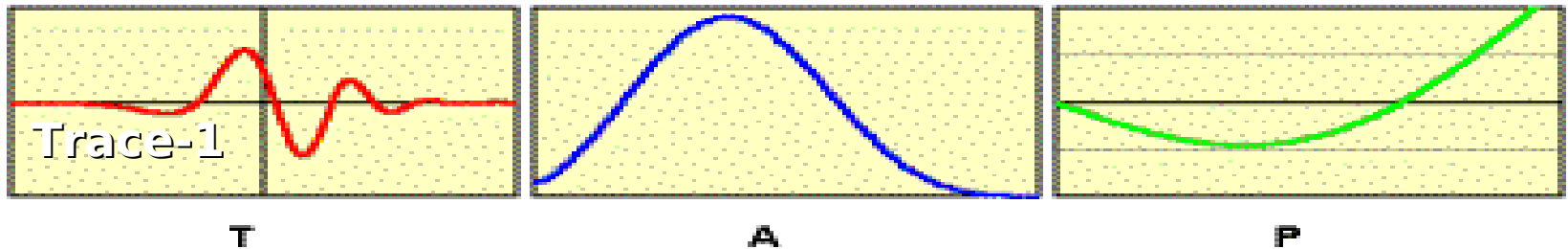


Residual Static Techniques

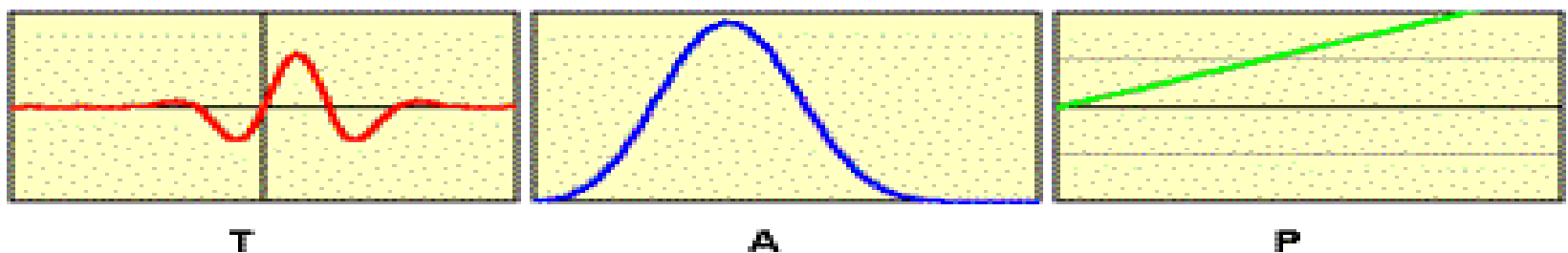
The most common methods of deriving the time-shifts and the resultant static values are:

- **Cross-correlation method**
- **Stack-power optimisation**
- **Combination of above**

Cross-Correlation



Cross-correlation of trace-1 & trace-2



Reflection Pick-Time Equation

- The time-shifts produced using the cross-correlation technique may be decomposed into shot and receiver statics by solving a set of simultaneous equations.
- For each trace the total residual static is derived from

$$T_{ij} = S_i + R_j + G_k + M_k X_{ij}^2$$

where

- S_i and R_j are the shot and receiver residual statics at shot i and receiver j respectively
- G_k is the structural term for k th CMP position
- M_k is the time-averaged RNMO at k th CMP
- X_{ij} is the offset from shot i to receiver j

Residual Statics Correction

Typical procedure -

1. First measure time-shifts (which are CMP consistent and sometimes called trim statics) between each trace within a CMP gather and a 'pilot' trace (usually the stacked CMP itself)

2. The picked times are then decomposed to Solve for the source and receiver statics in a surface-consistent manner

Stack Power Optimisation

(An alternative approach)

- **From an initial estimate of what the statics are and their equivalent stack response, there are several options on how the statics are perturbed in order to maximise the stack response.**
- **Available algorithms are:**
 - **Monte-Carlo based Simulated Annealing**
 - **Repeated One-dimensional Minimisation**
 - **Molecular Dynamic Simulation**

Maximising Modified Stack Response

A good set of static corrections result in higher amplitudes on the stacked trace compared to those from a poor set i.e. the stack response is improved.

The objective of Stack Power approach is to maximise the power of the stacked trace over the time window being analysed

To do this, a range of time shifts are tried for a specific source and receiver location, and the one that produces the highest stack power is chosen as surface-consistent residual static value for that location. This method is also known as “**Direct Reflection Statics Method**”

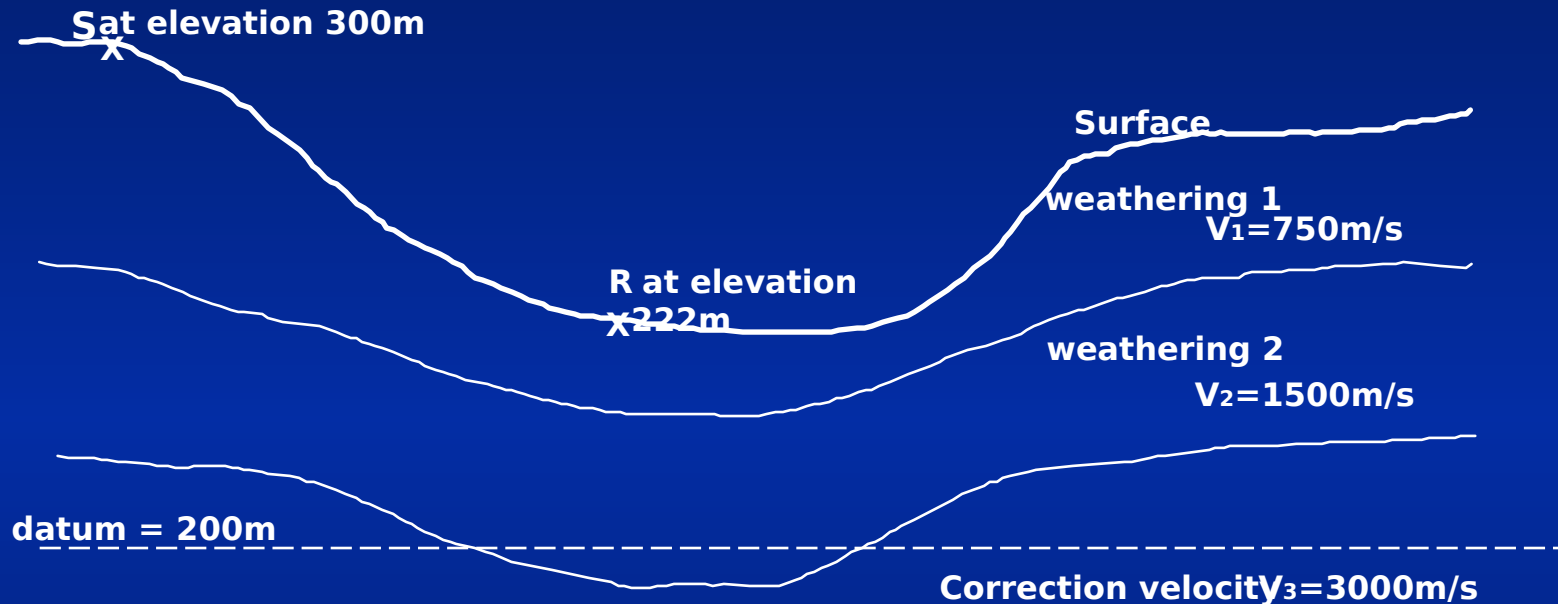
It assumes that NMO correction velocities are sufficiently accurate

Summary

Static corrections are required to :

- Place the sources and receivers at a common and known reference plane called
 - the **datum plane**
- Correct for near surface variations in velocity and consequently, timing of the seismic events
- Static corrections can be viewed as a 3-step process:
 - calculate initial statics (correcting for elevation and/or weathering from up-hole information)
 - refraction-based initial static (in addition to correcting for elevation/weathering, it helps remove long-wavelength anomalies)
 - reflection-based residual statics (corrections to remove any remaining short-wavelength static shifts to compensate for deficiencies left in the initial solution.

Practical exercise 2.



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At Shot location S At Receiver location R

Weathering 1 thickness 15 metres

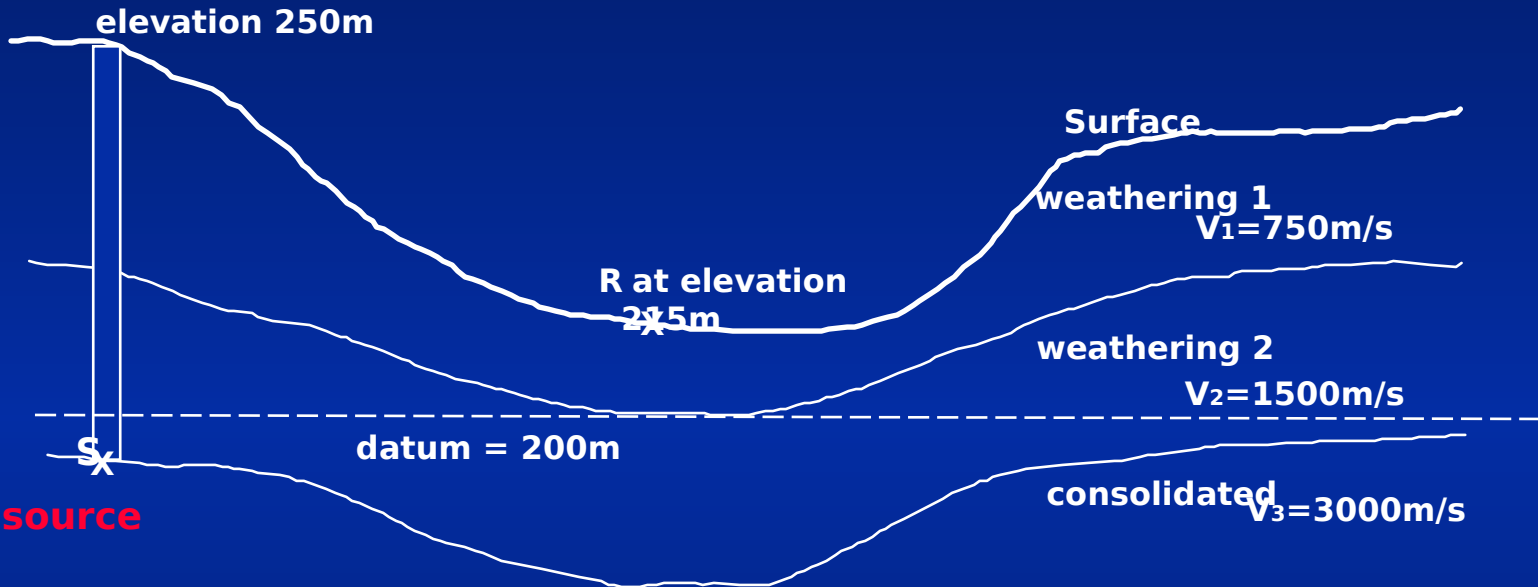
5 metres

Weathering 2 thickness 53 metres

37 metres

Calculate the total static for correction to datum for data originating at S and received at R. Remember the sign convention and compensation for weathering

Practical exercise 3.



At Shot location S At Receiver location R

Weathering 1 thickness 30 metres

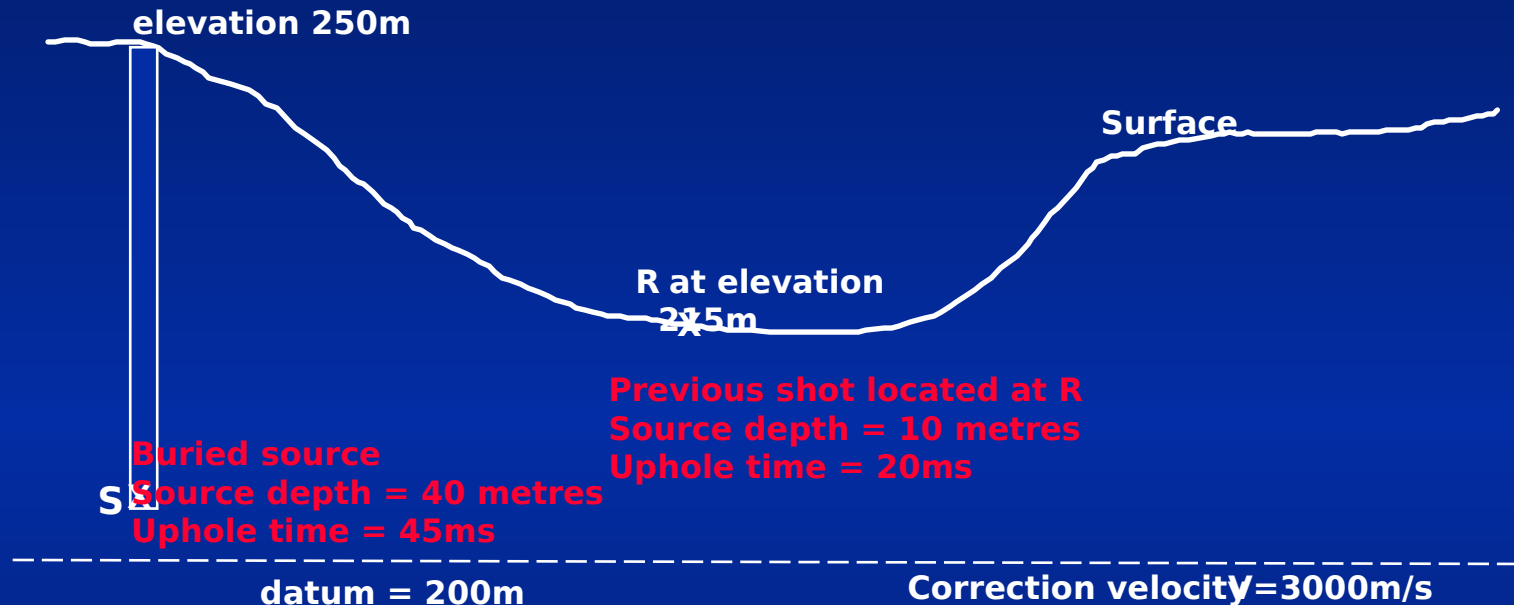
15 metres

Weathering 2 thickness 30 metres

37 metres

Calculate the total static for correction to datum for data originating at S and received at R. Remember the sign convention and compensation for weathering.

Practical exercise 4.



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At Shot location S At Receiver location R

Weathering thickness 40m

10m

Calculate the total static for correction to datum for data originating at S and received at R. Remember the sign convention.

Reference Material

In addition to CBT, you may wish to refer to the following presentations on the website:

Basic Statics

Individual Statics Theory